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NUCLEAR AND CONVENTIONAL ELECTRIC ENERGY IN BRAZIL

By Jerzy LEPECKI,
Assistant Professor of Electric Power Transmission
at the Institute of Electrotechnics of the School of Engineering
of the University of Minas Gerais,
former Chief of Electrical Studies and System Planning Section
of Centrais Elétricas de Minas Gerais S.A.
Associate Member of AIEE

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NUCLEAR AND CONVENTIONAL ELECTRIC ENERGY IN BRAZIL

Jerzy Lepecki

Assistant Professor of Electric Power Transmission at the Institute of Electrotechnics of School of Engineering of University of Minas Gerais, former Chief of Electrical Studies and System Planning Section of Centrais Elétricas de Minas Gerais S.A. Associate Member of AIEE.

1. INTRODUCTION

As in most countries today there is a steady demand for electric energy in Brazil. This problem is especially important in this country and other less developed areas as the growth in installed capacity and production should not only satisfy normal necessities of economic development but also cover an increase in "per capita" consumption which is now very small. Thus, during the last 10 years the production of electric energy increased at a rate of approximately 10% per year. The "per capita" capacity increased from 38,2 watts in 1952 to 55 in 1958 and to about 73 in mid 1962. At the moment there is no indication of decrease in this rate of growth. In fact, in some regions this increase is much faster.

Under these conditions and disregarding possible local variations it can be said that by 1969 some additional 5,000,000 kW should be installed in Brazil (5,162,212 kW being the installed capacity on May 30, 1962).

The question arises as how to best fulfill this task from the standpoint of the nature of power plants to be installed. In particular it is desirable to know whether construction of nuclear plants might speed up or in any other way help to attain the objective.

It is the purpose of this work to study this problem in the hope, that it might help to answer some of these questions.

2. OUTLINE OF BRAZILIAN ELECTRIC POWER SITUATION

a) South Central Region

The South Central Region comprises the States of Minas Gerais, São Paulo, Rio de Janeiro, Guanabara, Espírito Santo and part of Paraná. In it are concentrated the most important economic and cultural activities of Brazil. Its area is approximately 1,000,000 sq. km., and its population about 32,000,000.

Up to now, the most complete study of the South Central Region electric power situation has been made (finished in December 1961) under the auspices of Central Elétrica de Furnas S.A. by a consulting firm.

Its results are condensed in fig. I The installed capacity is, at present, about 3,600 MW. In fig. I are indicated the power plants under construction or already studied with estimated dates of beginning of operations of their several stages. As can be seen from comparison with the expected demand a deficit of installed capacity is expected, by 1968. Furthermore an even worse deficit in firm energy is to be expected by 1967. (The generation of hydro-plants for this case has been estimated on the basis of the critical period of a hydrological cycle equal to the second driest one in the region - 1943/1945).

In fig. I projects of Urubupungá with a first stage of 1258 MW now under construction and a second stage of 1440 MW and Estreito, already under studies by Furnas and with an installed capacity of 800 MW were not included.

It may be seen, nevertheless, that even with these plants, there still will be a deficit, by 1967-68, both in peak capacity and in firm energy, this last one being especially acute, in view of the plant factor of the hydro plants being around 50 or 60%.

From the foregoing it is seen that the plants now under construction or in an advanced stage of planning will not be sufficient to cover the power deficit foreseen in 1967 for the South Central Region of Brazil.

In order to be able to cover this deficit, a plant of about 500 MW capacity must be planned, designed and built in a period of four to five years. It should be noted, furthermore, that 250 MW are needed as soon as the construction is completed. It is also seen that the plant factor of this power plant will be very high, though depending on the hydrological conditions. In the critical period considered it should be almost 100%. Owing to the relatively low plant factors of existing hydro plants it may be assumed that the plant factor of the new plant might be around 65-70%. As a matter of fact one of the recommendations of the above mentioned study is that in future, more high plant factor power plants should be installed in the South Central Region.

How can the installation of this additional capacity be best achieved?

Large hydro plants such as Três Marias (520 MW) and Furnas (1200 MW) take from 6 to 8 years to design and build.

In the South Central Region there are several sites for hydro plants with capacities equal to or higher than 500 MW. Some of them are already reasonably studied. As an example we can mention the Caraguatatubas project on the Paraiba river in the State of São Paulo, with 500 MW capacity and a plant factor of about 50% and Marimbondo project on the Grande ri-

ver in the State of Minas Gerais, with 600 MW capacity and a plant factor of about 60% due to regularization of the river by upstream projects.

It is believed that, from the technical point of view, if a concentrated effort is begun now, the Caraguatatubas project might start operation around 1968-69 and Marimbondo around 1969. This latter one would be built almost simultaneously with Estreito project.

It is seen, then, that it would be rather difficult to build a hydro-plant in time to cover the deficit. The energy production of each of the plants would be also too small, unless the two plants were built at the same time.

In the South Central Region there are more sites that were reasonably studied and probably, many more that were not studied at all. Especially on the Grande River many sites were studied with a total installed capacity of 7000 MW, Estreito and Marimbondo being representative of the larger ones. Nevertheless, it seems that it will be very difficult to build one or more hydro plants in time to cover the deficit foreseen in the region, starting with 1967. All the same, it is important that these sites be fully developed and construction started as soon as possible, in order to be able to keep up with the ever growing demand of the region. These plants, even though not best suited to cover the immediate need because of the time factor involved are necessary to supply part of the demand beyond 1970, being also very economic - cheap to build, located close to load centers and regulated by Furnas, thus being able to work at high plant factors.

Thus, it seems that even though the South Central Region is very well endowed with hydro resources (+), it might be necessary to build a thermal plant in order to have it ready by 1967.

A thermal plant of 500 MW capacity could be built in four years and thus be ready just in time.

The building of thermal plants in Brazil, especially of this size, is not very popular because of the lack of fuel, which has to be imported in great part, and because of great abundance of hydro potential. The usual way to operate a thermal plant would be with a low plant factor, to complement hydro generation and save as much fuel as possible. Nevertheless, under conditions of growth found in the South Central Region, this kind of operation is not always feasible and the only big thermal plant in Brazil (Piratininga with 450 MW, located in the State of São Paulo), operates on base load. As stated earlier it is reasonable to assume that the average plant factor would be about 65%, being higher at the beginning, especially if a critical period occurs. In normal hydrologic years the factor would be lower and some fuel might be saved.

Once admitted the construction of a thermal plant there immediately occurs the question of it being a nuclear plant.

Such a plant could be built in about five years and thus, though later than a conventional thermal plant, it might start its operation earlier than a hydro-plant. This last fact is not very certain because, while the technique of building hydro plants is quite well developed in Brazil, this, of course, is not the case as far as construction of nuclear plants is con-

(+) About 20,000,000 kW of hydro.

cerned. In fact, construction of a nuclear plant of this size constitutes a major engineering problem anywhere in the world. Nevertheless, with the help of entities abroad which have already faced this kind of problem, it might be assumed that a nuclear plant would be built somewhat earlier than a hydro plant. A discussion of economic factors is made in paragraphs 3 and 4.

Here, I would like to point out that there exists, in Brazil a notorious shortage of fossil fuels and thus, if at all feasible, it is highly desirable to save them for applications where they cannot be substituted. On the other hand, the electric power situation, outlined here will, if anything, grow more acute and in the decade 1970 - 1980 about 1000 MW per year should be installed in the South Central Region of Brazil. In order not to disperse the scarce capital and human resources it would be highly desirable to build in the region big plants of at least 500 MW. In this way, many of the hydro sites in the range of 100-200 MW even though feasible from other points of view, will be not worth while to develop owing to the time involved out of proportion to their size (+). For this reason as well as because of economies in capital investment, larger and more remote sites will be developed, and more big thermal plants, close to the load centers will have to be built. A proportion of these plants will probably be nuclear.

b) Northeastern Region

The Northeastern Region is a vast region of about 1,500,000 sq. km. with a population of 22,000,000. The power problem in this region is rather acute, but the solution is not easy because of very low load concentration.

The Federal Government is promoting the construction of several dams for water storage all over the area. These dams are also utilized to produce power. Several steam and diesel plants have also been installed in the region.

The Federal Government through the "Companhia Hidroelétrica do São Francisco", CHESF, is building the Paulo Afonso hydro plant. This plant will have an ultimate capacity of 1,530,000 kW. The present capacity is 330 MW and the firm capacity is estimated at about 900 MW. In this latter estimate is included the regulating capacity of Três Marias dam recently completed and located on the upper São Francisco in the State of Minas Gerais.

In fig. II, the demand forecast for the region and the steps of expansion of Paulo Afonso plant are shown. The load foreseen for city of Fortaleza, capital of Ceará, 700 km from Paulo Afonso is included in the forecast. On the other hand, the two northernmost States of the region -Piauí and Maranhão - are not included, but their effect on the total is rather small.

(+) This does not apply to many sites of this size, located downstream from big reservoirs such as Três Marias and Furnas. Plants built in these sites will have water regulated by these reservoirs and will be able to work at high plant factors, thus producing large quantities of firm energy

It is seen that the Paulo Afonso plant will be able to supply the demand up to 1970, even if the present fast rate of growth is maintained. After Paulo Afonso is completed, at least two other hydro plants can be built in the same region - Itaparica and Curituba with a total of, approximately, 3,500 MW. Thus, it is apparent, that there is no problem as far as generation is concerned. On the other hand, the problem that might arise, both technical and economical, would be concerned with transmission of this power to the load centers.

Nevertheless, as will be seen later on, the characteristics of Paulo Afonso - low dam, high head and large installed and firm capacities - are such that its power unit cost is exceptionally low. This means that relatively more may be spent on transmission. As far as technical problems are concerned, they are not difficult to solve. As a matter of fact, a 700 km transmission line does not present, nowadays, any special problem, except of course, higher investment costs.

It is desirable, on the other hand, that some local generation be installed at the extremities of these long transmission lines and in other points of the area in order to ensure better reliability, better voltage control and better overall operation: This local generation will be obtained from the small power plants both hydro, installed at the water storage dams, and thermal, as mentioned above.

From this picture it is seen that there is no place for installation of medium and large thermal power plants in the region. This is so because there is no load concentration large enough that might justify the installation of a plant of 100 MW or more and which would not need relatively long transmission lines. Only such a plant might compete with Paulo Afonso, even with its high transmission costs. This is especially true of nuclear power plants.

The only exception might be the city of Fortaleza, where a 100MW plant could be installed.

We shall see, later on, the economic aspects involved in this last case. At present, it can be said that because of low load densities and because of exceptionally low cost of Paulo Afonso plant, nuclear power could not bring much help to the electrification of the Northeastern Region of Brazil.

c) Southern Region

This region comprises part of the state of Paraná and the States of Santa Catarina and Rio Grande do Sul. It has an area of approximately 500,000 sq. km. and a population of 11,000,000. It has a reasonable amount of hydro potential as well as some coal deposits, mainly in Santa Catarina and Rio Grande do Sul. An interesting feature of these deposits is that it is difficult to increase the production of the high grade metallurgical coal because there is not enough demand for the low grade steam coal that is left as by product.

Each of the three States of the Region has its own plan of electrification. The rate of growth of the load is comparable to that of the South Central Region but the capacities involved are much smaller. The greatest blocks of power are needed in Rio Grande do Sul, the biggest and

most developed of the three States. See fig.III for the foreseen demand and plants scheduled for construction through the Electrification Plan of the Rio Grande Electric Energy Commission. It is seen that the demand can be supplied without difficulties by these plants.

Santa Catarina is a small State and its power requirements can be readily supplied by small hydro and thermal plants already installed or under construction.

Paraná has at present about 150 MW of installed capacity mostly small hydro and thermal plants and interconnections with the States of São Paulo and Santa Catarina. The State Government has scheduled to install small and medium hydro and thermal plants with a total capacity of about 500 MW, by 1970. In this capacity is included part of Chavantes hydro plant being built in São Paulo. These plants should adequately cover the foreseen demand.

The supply of electric energy in the Southern Region is thus assured until 1970 if the plans are fulfilled. Nevertheless, questions arise as to the feasibility of giving greater emphasis to construction of thermal plants in view of the coal deposits located at convenient distances, as well as to possibilities of nuclear power. We shall review some of these problems in the next paragraphs.

3. ECONOMIC CONSIDERATIONS

a) General

In this paragraph some costs of electric energy in Brazil have been estimated. For these estimates, a plant of 100 MW and another of 500MW have been chosen these being the capacities that might be most readily employed in the regions of Brazil studied in the preceding chapter.

The costs per installed kW of nuclear plants have been based on Reference 1, other technical literature and contacts with manufacturers. The cost for conventional thermal plants was obtained from latest surveys in technical magazines. In both cases, adjustments have been made to take into account the change of conditions from countries where the published prices apply and Brazil. For this purpose, the estimated costs of engineering, land and civil works have been deducted from the total price, after which shipping and import expenses and the cost of land and civil works in Brazil and engineering previously deducted have been added and the total price has been obtained.

The estimates for nuclear power have been reasonably close to other estimates made in Brazil. For the conventional thermal power, the estimates check quite well with costs calculated for existing projects.

As for hydro plants, the costs have been estimated with basis on several projects already built, under construction, and planned, with information on costs both published and private, obtained from the entities involved.

All costs have been reduced to conditions at beginning of 1962 and the Brazilian currency cruzeiro has been converted at a rate of US$.... 1,00 = Cr$ 300,00.

The annual plant factors assumed for 100 MW plants are 50% and for 500 MW 65%. The 100MW plant is supposed to operate in a smaller system,

or completely isolated.

b) Cost of Nuclear Energy

Both natural uranium, graphite moderated CO2 cooled and enriched uranium Boiling Water Reactor type, nuclear plants have been considered.

For natural uranium cycle, the following assumptions have been made:

Cost of nat. uranium	US$ 23.5/kg
Fabrication	US$ 16.0/kg
Shipping	US$ 18.0/kg
Total	US$ 57.5/kg

The cost per kwhr assumes cost of 1.5 cores. The burn-up assumed is of 3000 MWD/t, efficiency of plant 30%.

For enriched uranium a 2% enriched fuel is assumed:

Initial value (2%)	US$146.50/kg
Final value (1%)	- US$ 47.70/kg
Plutonium credit (0.5%) US$ 9.5/kg	- US$ 47.50/kg
Fabrication	US$ 92.00/kg
Shipping	US$ 18.00/kg
Reprocessing	US$ 33.10/kg
Total	US$194.40/kg

Again the cost of 1.5 cores was assumed for the calculation of cost per kWh. Use charge of 4,75% has been applied and a fuel cycle of 5 years, burn-up of 13,000 MWD/t and efficiency of 30% have been assumed.

c) Cost of conventional thermal energy

For estimate of fuel costs, three locations have been assumed: a location close to the seaside, a location in interior of Rio Grande do Sul and a location in interior of Santa Catarina, close to coal mines in both cases.

At seaside, oil has been assumed as fuel, coal being the fuel at interior locations. Prices of oil and coal have been furnished, respectively, by "Conselho Nacional do Petróleo" and "Comissão do Plano do Carvão Nacional". Price of oil is Cr$ 1.2 per 1000 kcal and of coal Cr$ 1.00 at the mine in Rio Grande do Sul and Cr$ 0.50 at the mine in Santa Catarina.

Heat rate of 100 MW plant is assumed as 2,625 kcal (10,500 BTU)/net kwhr and that of 500 MW plant as 2,375 kcal (9,500 BTU) net kwhr.

The plant in Rio Grande do Sul has been assumed more expensive than either the plant in Santa Catarina or the oil fueled plant, because of poor quality of coal in this State.

For heat values of fuel were taken 10,200 kcal per kg of oil, 2,600 kcal/kg of coal in Rio Grande do Sul and 6,090 kcal/kg for coal in Santa Catarina.

d) Other Expenses

Among other expenses, the most important is the cost of money. This is very difficult to establish in Brazil, because of the problems caused by inflation. The official regulations state that the return on capital in electric utilities must not be higher than 10% of the capital invested uncorrected for inflation. On the other hand, more than 20% can be obtained in many other investments but, of course, this high rate is partly accounted for as a means of protection against inflation. Nevertheless, supply of capital is rather scarce in Brazil and this should be reflected in higher interest rates. For this reason, the costs of kwhr have been calculated for what might be considered the two extremes: 10% and 20% of interest.

Depreciation is calculated for a life of 25 years for nuclear plants, 30 years for conventional steam plants and 40 years for hydro plants. The sinking fund method is used. Taxes are very low (about 0.1% of capital cost), as Government owned utilities are assumed in this study.

4. DISCUSSION OF THE RESULTS

a) General

In Table I. are condensed the results of cost studies. From them, the following conclusion is immediately apparent: hydro plants produce power incomparably cheaper than other kinds of plants. Next to it, the power produced by coal fueled plants in Santa Catarina is the cheapest. In fact, this is the only kind of thermal plant that might be compared with hydro in Brazil.

Nuclear power seems to be competitive with conventional thermal power. Power from BWR is less expensive than power from the Natural Uranium reactor.

As far as our study is concerned, the following conclusions can be drawn:

b) South Central Region

A 500 MW nuclear plant, installed in this region would be competitive with a 500 MW conventional thermal plant. An enriched uranium plant produces power considerably cheaper than the conventional thermal plant, for both values of rate of interest assumed. Power produced by Natural Uranium Reactor is very slightly more expensive than that produced by conventional plant for interest rate of 10% and is considerably more expensive for a rate of 20%.

These figures, being estimates, are necessarily approximate but it seems that the conclusion can be drawn that nuclear plants, especially of the Enriched Uranium type, certainly are competitive from an economic point of view, with conventional thermal plants in the South Central Region. This means that, whenever the installation of a thermal plant is envisaged, consideration should be given to a nuclear plant.

Nevertheless, it is seen that thermal plants, both conventional and nuclear produce much more expensive power than the hydro plants and thus should be built only for reasons sufficiently strong to overrule the stric-

tly economic considerations. In the particular case of the 500 MW nuclear plant the possible reasons for its construction - economy in time - might not be decisive because at present it is not yet clear whether a plant of this size could be ordered, designed, shipped and installed in a time much shorter than that required for a hydro plant.

Thus, taking into account the abundance of hydro reserves in the South Central Region, it would seem more advisable to concentrate on hydro plants, with every effort to build them in time and, if necessary, supplement them with medium size conventional thermal plants, which might be built faster and once in operation, might constitute a certain reserve in the system, economising fuel, when sufficient hydro is installed.

c) Northeastern Region

As it can be seen from Table I, Paulo Afonso plant produces extremely cheap power and no other plant, thermal or hydro, produces power at this cost. Thus, it is quite clear that this power should be used before other kinds of plant be considered.

Rough calculations indicate that even the relatively uneconomic 700 km transmission line from Paulo Afonso to Fortaleza, transmitting 100MW at 50% load factor, would increase the cost of power to 10,40 mills/kWh for interest rate of 10% and to 21,00 mills/kWh for the rate of 20% which is still cheaper than comparable amount of power produced by thermal plants.

d) Southern Region

In this region, a 100 MW nuclear plant might be installed in substitution of some of the plants already scheduled for installation. Nevertheless, even in this region of relatively high cost hydro (due to small sizes of available sites), hydro power is cheaper. Nuclear power is slightly more expensive than conventional thermal power installed at mine mouth in Rio Grande do Sul.

Special consideration should be given to coal fired plants in Santa Catarina where higher grade coal mines exist and where the power produced in this way is very cheap. It is interesting to note that even with a 250 km transmission line delivering 100 MW at 50% load factor from Capivari mines in Santa Catarina to Porto Alegre in Rio Grande do Sul, the power would be delivered at about 13.0 and 19.3 mills for 10% and 20% interest respectively, which still is cheaper than other thermal power both conventional and nuclear and is almost competitive with hydro.

This means that Santa Catarina might be an exporter of electric power to the neighbouring States, if economic hydro sites become scarce in the region.

5. GENERAL CONCLUSIONS

We have thus seen that the only region in Brazil, where nuclear power might have some use, at this time, is the South Central Region. Nevertheless, both conventional thermal and nuclear plants produce power so much more expensive than hydro, that every effort must be made, at present, to solve the electric energy problems by means of hydro plants. (A small amount of thermal power might be required to improve system reliability).

An exception to this situation is Santa Catarina, where coal fired plants may produce reasonably cheap power.

It is the author's opinion that, in order to improve the electric power situation in Brazil, making the best use of available science and technology, the following program should be carried out (especially important for the South Central Region):

i) A thorough study of Brazil's real availabilities ofhydro potential be made especially as far as the building of big plants (500 MW and up) is concerned.

ii) A complete interconnection of existing systems should be made in order to utilize in the most economic manner the existing generating capacity and in order to be able to utilize most conveniently the power generated by the big plants to be built.

iii) A study of the most efficient and uniform construction methods should be made, as well as standardization of design of hydro plants, in order to decrease the time and effort necessary to build them.

iv) A vigourous effort should be made to solve the Brazilian fue situation both oil and coal. (First steps were already taken in this direction and Brazil is now producing about 32% of its oil consumption).

v) The nuclear program already under way should be continued and expanded in order to have sufficient manpower and scientific and technological knowledge necessary to choose, order, and supervise the building at first, and later on to design and build power reactors. All efforts should be made to select the most appropriate reactors for Brazilian conditions and to use as much as possible domestic technology and materials. In particular, an intensive program of prospection for uranium and other nuclear fuel ores should be carried on.

vi) The capacity of Brazilian heavy electric industry should be expanded in order to be able to manufacture in Brazil the big generators and turbines that will be necessary (Brazilian industry can already produce large hydro generators. Nevertheless, it will be necessary to produce large water wheels, steam turbines, and turbogenerators). Local industry should also be able to manufacture greater part of other components of thermal plants, both conventional and nuclear.

REFERENCES

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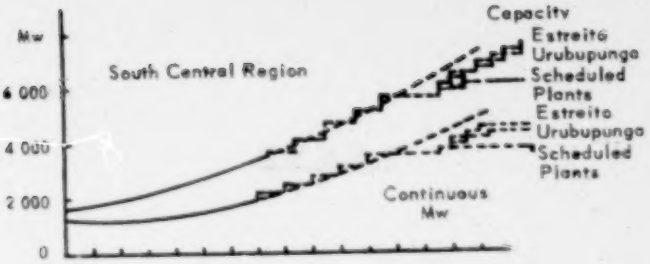

Fig. I

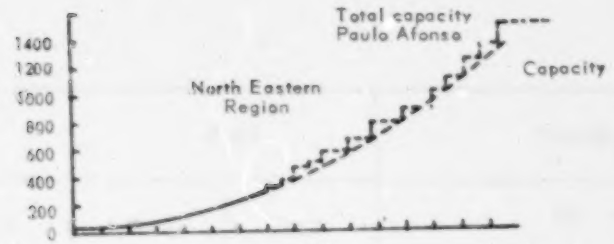

Fig II

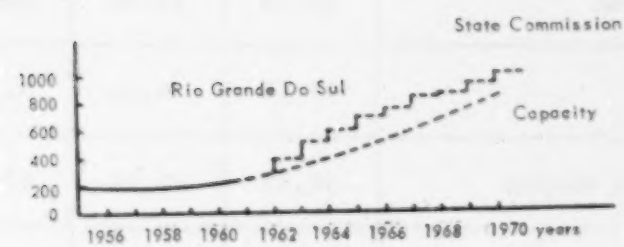

Fig III

TABLE

Cost of power in mills per kwhr

INTEREST	10 %		20 %	
Capacity - MW	100	500	100	500
Nat. Uranium	21.13	13.55	36.77	22.57
BWR	17.15	8.63	29.32	13.37
Thermal-oil fueled	16.73	13.26	22.10	16.38
Thermal-coal fueled				
a) Rio Grande do Sul	15.23	11.87	20.80	15.15
b) Santa Catarina	10.85	7.91	16.42	11.19
Hydro-South Central Reg.	8.62	5.50	18.20	11.49
Paulo Afonso - 900 MW	5.66		11.72	

1680 E - Nov.1962 - 1,600